Anthropogenic aerosols

Indirect warming effect from dispersion forcing

Anthropogenic aerosols enhance cloud reflectivity by increasing the number concentration of cloud droplets, leading to a cooling effect on climate that is referred to as the Twomey effect[1,2]. Here we show that anthropogenic aerosols exert an additional effect on cloud properties that is derived from changes in the spectral shape of the size distribution of cloud droplets in polluted air and acts to diminish this cooling. This finding could help to improve our understanding of the indirect aerosol effect and its treatment in climate modelling.

An equation commonly used for examination of the indirect aerosol effect is

$$r_e = \beta[3/(4\pi\rho)L/N]^{1/3} \qquad (1)$$

where ρ is the water density, r_e is the effective radius, L is the cloud liquid-water content and N is the number concentration of cloud droplets. The parameter β is an increasing function of the relative dispersion (ε) of the cloud droplet size distribution (ratio of the standard deviation to the mean radius), which is well described[3,4] by

$$\beta = (1 + 2\varepsilon^2)^{2/3}/(1 + \varepsilon^2)^{1/3} \qquad (2)$$

An increase (decrease) in effective radius causes a decrease (increase) in cloud reflectivity[1,2]. A prevailing assumption implicit in the evaluation of the indirect aerosol effect is that increasing aerosol loading does not alter ε or, hence, β. However, examination of data from field studies of the indirect aerosol effect shows that marine clouds classified as being polluted or having a continental origin generally have not only a larger N, but also a larger ε relative to unaffected marine clouds.

Figure 1 shows the dependence of ε and β on N. The points connected by lines represent cases identified by different investigators as evidence for the indirect effect. In each case, the points with lower N were characterized as background clouds and the higher points were characterized as similar clouds that had been perturbed by anthropogenic aerosols. Eleven of the 13 cases show an increase in ε that is concurrent with an increase in N, with negligible change to slight decreases in the other two; there is also a general increase in ε with N, as implied previously[5–7].

One explanation for the simultaneous increase in ε and N is that anthropogenic aerosols have a more complex chemical composition and a broader size distribution than marine aerosols, and that the more numerous small droplets formed in a polluted cloud compete for water vapour and broaden the droplet size distribution compared with clean clouds that have fewer droplets and less competition.

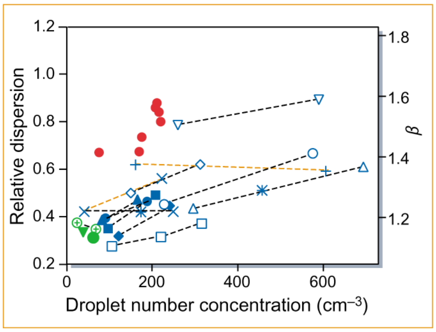

Figure 1 Relation between the relative dispersion of cloud droplet size distribution, ε, and the number concentration of cloud droplets, N. Symbols indicate programs and/or references from which the data points were derived. Connected points represent cases previously identified as evidence for an indirect aerosol effect. The parameter β is defined by equation (2). Green symbols (from ref. 8): triangle, FIRE, northeastern Pacific; crossed circles, SOCEX, Southern Ocean; filled circle, ACE1, Southern Ocean. Blue symbols: filled circles, ASTEX[8], northeastern Atlantic; diamonds, SCMS[8], Florida coast; filled triangles, Sounding[9], ASTEX; filled squares, horizontal[9], ASTEX; open inverted triangles, level 1; open upright triangles, level 2; open circles, level 3 — all from southwest of San Diego[10]; open diamonds, SCMS[11]; stars, vertical, ASTEX[12]; plus signs, horizontal, ASTEX[12]; multiplication signs, ASTEX[13]; squares, INDOEX, Indian Ocean (G. M. McFarquhar, personal communication). Red circles, MAST[6,14,15], California coast.

According to equations (1) and (2), an increase in ε acts to negate the effect of increased N on effective radius and cloud reflectivity. Because this effect has been largely neglected in estimates of the indirect aerosol effect, cooling by an indirect aerosol effect is likely to have been overestimated. From the data presented in Fig. 1, we estimate that a 15% increase in N at $N = 100$ cm^{-3} causes a total forcing that ranges between -0.19 and -0.93 W m^{-2}, which corresponds to a factor that is 10–80% lower than the -1.03 W m^{-2} calculated for the Twomey effect alone[2].

The effect of the enhancement in ε is evidently large enough to be considered in assessing the indirect aerosol effect, and understanding the relation between ε and N will help to reduce the large uncertainty inherent in this effect.

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